THE HEMIPTERA OF BRACKNELL AS AN EXAMPLE OF BIODIVERSITY WITHIN AN URBAN ENVIRONMENT

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ABSTRACT

There is a relative lack of information regarding the biodiversity of arthropods within urban areas. In this study an initial assessment was made of the species richness of Hemiptera on roundabouts within the town of Bracknell. Hemiptera were collected from grassland using suction sampling and from arboreal habitats using a tree beating technique. Comparison of species-richness estimators indicated that the Jack-knife 1 was the best suited for this system. A total of 138 species was recorded, although comparison of estimated and observed species-richness indicated that 52 more species may have been present but un-recorded. An additional 49 species, recorded at other times, are known from the town, giving an known species richness of 187. Overall, even with relatively limited sampling, it is estimated that Bracknell supports at least 20% of the UK's Hemiptera species.

INTRODUCTION

With the exception of work on synanthropic pest species, the study of insects and other arthropods within urban environments has been a relatively neglected area of study, despite the large and ever increasing size of such areas (Davis, 1976; McIntyre, 2000; McIntyre *et al.*, 2001). Those studies that have been published have reported that considerable insect biodiversity exists within towns and cities (Davis, 1976, 1978; Zapparoli, 1997; McIntyre, 2000).

Urban areas consist of a heterogenous mixture of habitat types such as buildings, transport infrastructure, parks, gardens and unused areas sometimes referred to as waste ground (Owen & Owen, 1975; Zapparoli, 1997; McIntyre, 2000). These of course vary in their species richness and diversity, and the overall balance between land use types has an important effect on the relative biodiversity of different parts of urban areas (Davis, 1978; McIntyre, 2000). Within each habitat or habitat patch many factors have been suggested as important in determining the relative species richness and diversity including the levels of isolation and fragmentation, management practices, disturbance, and habitat type, age, area, diversity and connectivity, as well as the characteristics, such as relative mobility, of different taxonomic groups (Davis, 1976; Davis & Glick, 1978; Zapparoli, 1997; Denys & Schmidt, 1998; Fernandez-Juricic, 2000; McIntyre, 2000; Savard *et al.*, 2000; Rudd *et al.*, 2002; Whitmore *et al.*, 2002).

Species-richness is one of the most important and frequently used measures of biodiversity (Magurran, 2004). Quantifying the total species-richness of a given study system is however, frequently difficult and costly. Consequently it is common practice to employ species-richness estimation methods to gain a measure of the true species richness from a limited number of replicated samples (Foggo *et al.*, 2003; Petersen & Meier, 2003; Magurran, 2004). A number of these estimation methods have been developed, including a range of non-parametric estimators (Colwell &

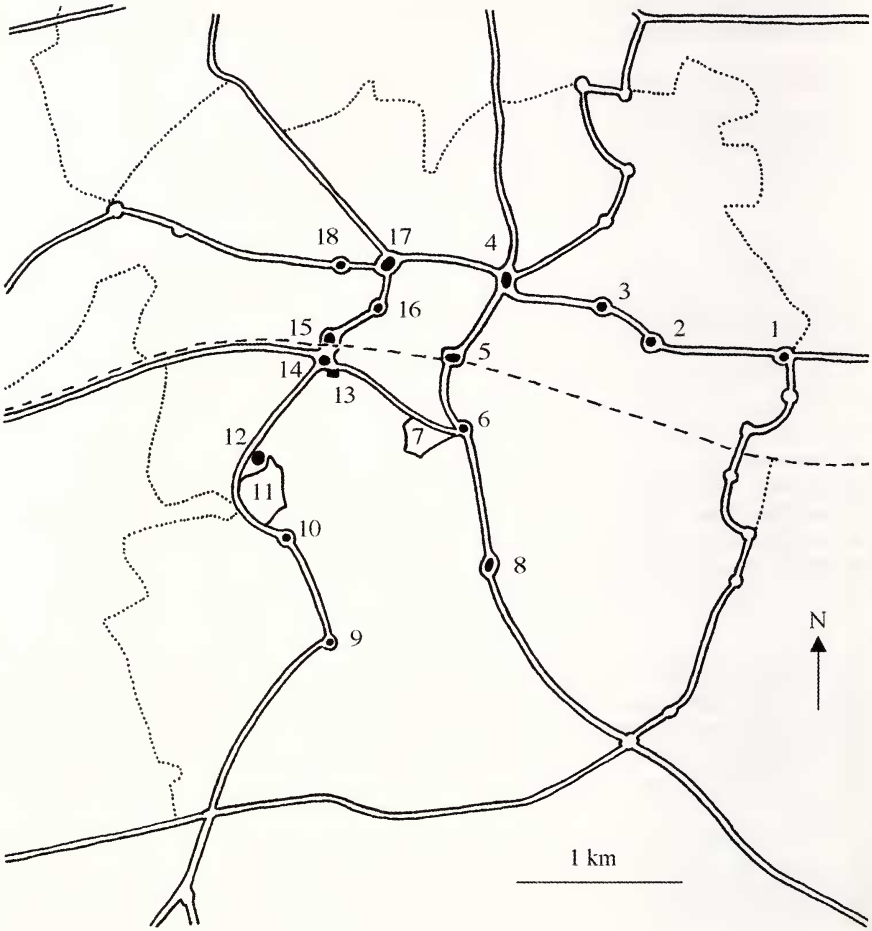

Figure 1. Map of Bracknell showing the position of the 18 sample sites. Roads are shown with solid lines, the dashed line is a railway, and the dotted lines indicate the outer edge of the urban area. To the north and west of the town the land use in principally agricultural, while to the south and east there are large areas of forestry. Sample sites: 1, Baldocks roundabout; 2, Running Horse roundabout; 3, Eastern Road roundabout; 4, Meteorological Office roundabout; 5, Bracknell Station roundabout; 6, Broad Lane roundabout; 7, Bill Hill; 8, Bracknell Sports Centre roundabout; 9, Hanworth roundabout; 10, Mill Pond roundabout; 11, Mill Pond Park; 12, Mill Lane slip road; 13, Downshire Way; 14, Twin Bridges roundabout south; 15, Twin Bridges roundabout north; 16, The Point roundabout; 17, 3M roundabout; 18, Arlington roundabout.

Coddington, 1994; Magurran, 2004). Evaluation of the various estimators, using a variety of taxa, has been equivocal, with different estimators being judged the most useful in different contexts (Colwell & Coddington, 1994; Condit *et al.*, 1996; Walther & Morand, 1998; Longino *et al.*, 2002; Foggo *et al.*, 2003).

In this study the species-richness of Hemiptera (Auchenorrhyncha, Heteroptera, Psylloidea) of roundabouts within the town of Bracknell, England was estimated using four non-parametric species-richness estimators, Chao 1; Chao 2, Jack-knife 1; and Jack-knife 2. Hemiptera were chosen as a diverse, abundant and easy to collect group of insects (Morris, 1971; Duelli, *et al.*, 1999; Fauvel, 1999), which has been relatively little studied in urban areas (McIntyre, 2000). The Chao 1 estimator was chosen given its overall good performance (Foggo *et al.*, 2003), and Chao 2 and Jack-knife 1 and 2 have been found to be particularly useful when sampling is limited (Colwell & Coddington, 1994; Walther & Morand, 1998). Given the time constraints of the study it was not possible to gain a complete enough inventory of species to accurately assess the performance of estimators directly, but it was possible to gain some measure of their relative merit by comparing the estimates from overall and habitat based samples, and to use the estimates to generate species-area relationships for comparison with those previously described for the same study system by Helden & Leather (2004).

Methods

Bracknell is a town located in southeast England between latitude 51°23′ and 51°26′ N, and longitude 0°43′ and 0°47′ W. It is part of the unitary authority of Bracknell Forest, which also includes several other smaller settlements, as well as considerable areas of farmland, heathland and forest. Although a settlement did exist earlier, it was the New Towns Act of 1946 that led to the great expansion of the town to its present population of approximately 52 000. Despite the urbanisation and population growth, the development of the town of Bracknell has been managed in such a way as to preserve several large parkland areas and numerous smaller open areas, and it has also retained a very large number of trees.

Table 1. Details of the names and locations of the sample sites.

Site number and name		Grid reference	Area (m^2)
1	Baldocks roundabout	SU891689	401
2	Running Horse roundabout	SU883691	1962
3	Eastern Road roundabout	SU880693	1800
4	Meteorological Office roundabout	SU874695	6275
5	Bracknell Station roundabout	SU871689	5198
6	Broad Lane roundabout	SU871685	4132
7	Bill Hill	SU869684	43 574
8	Bracknell Sports Centre roundabout	SU873677	3866
9	Hanworth roundabout	SU863671	2165
10	Mill Pond roundabout	SU860678	2050
11	Mill Pond Park	SU859681	63 681
12	Mill Lane slip road	SU858683	7118
13	Downshire Way	SU863688	4340
14	Twin Bridges roundabout south	SU863690	3268
15	Twin Bridges roundabout north	SU863691	2144
16	The Point roundabout	SU867693	489
17	3M roundabout	SU867695	5016

Figure 2. Mill Pond roundabout (site 10) was typical of many roundabouts, with no pedestrian access.

Figure 3. Twin Bridges roundabout south (site 14) was representative of several roundabouts which were sunk below the level of the road and dissected by one or more pedestrian/cycle paths accessed via subways.

The study sites were 18 more or less road-enclosed areas, 14 of which were roundabouts (Fig. 1). These sites were selected as part of a study of species-area relationships (Helden & Leather, 2004). The four non-roundabout sites were: Bill Hill (7), an area of woodland and parkland enclosing an ancient monument; Mill Pond Park (11), which is a park containing a mixture of grassland and woodland surrounding a large lake; Mill Lane slip road (12), which is an area of grassland interspersed with mature willow trees (*Salix*), and which is very like a roundabout as it is completely surrounded by a major road and a curved slip road; and Downshire Way (13), a small patch of unused land that has been widely planted with trees but contains quite a large area of completely unmanaged grassland. Further details of the sites are shown in Table 1. Two typical roundabout sites are illustrated in Figures 2 and 3.

Grassland Hemiptera were sampled between 15 and 17 July 2002, using a Vortis Insect Suction Sampler (Burkard Manufacturing Co Ltd, Rickmansworth, Herts, UK) (Arnold, 1994). A five second sample was taken at ten randomly chosen points on each of either four or eight transects per site, and the total catch from a single transect was retained as one overall sample. The number of transects was dependent on the number of management regimes present, with four transects per regime.

Prior to sampling arboreal Hemiptera, the location and species of all trees at the 18 sites, that could be sampled and were not enclosed within larger blocks of woodland, were recorded. Then at each site between one and four trees of each species were sampled by vigorously beating part of each tree for five seconds above a sweep net (45×60 cm) and then collecting all the adult Hemiptera from the net with a pooter. All arboreal Hemiptera sampling was done between 13 and 20 July 2002.

In addition to the systematic sampling of grassland and arboreal Hemiptera in the summer of 2002, a number of additional species were recorded on a more casual basis between 1996 and 2002. Samples were collected at various times of the year and from a range of terrestrial habitats including from bushes and various ruderal plants that were not sampled during the main study.

Insects were identified using Leston & Scudder (1956), Southwood & Leston (1959), Wagner & Weber (1964), Le Quesne (1960, 1965, 1969), Le Quesne & Payne (1981), Hodkinson & White (1979), Ossiannilsson (1981), Miller (2001) and Nau (2002b), and are listed according to Hodkinson & White (1979), Le Quesne & Payne (1981) and Nau (2002a).

Maximum species estimates were made by calculating the Chao 1, Chao 2, Jack-knife 1 and Jack-knife 2 species richness estimators, using EstimateS version 6.0b1 (Colwell, 2001). Overall Bracknell roundabout species-richness was estimated for each of the three Hemiptera groups using all the replicated samples from all sites and habitats. Similar estimates were also made for the two principal habitat types, grassland and arboreal, using all the samples from all sites from each habitat.

To enable comparison with the previously published species-area relationship of arboreal Hemiptera at these sites (Helden & Leather, 2004), maximum species-richness estimates were made for arboreal Hemiptera only, using samples within each site as replicates. In this case the three Hemiptera groups were combined in each sample. Regressions between species-richness estimates and log (ln) area and the log (ln) number of tree species were carried out using the R statistical package (version 1.7.1) (Ihaka & Gentleman, 1996). The area and tree species data were taken from Helden & Leather (2004).

An estimate was made of the relative area of land, within the town of Bracknell, under the following categories of land use: buildings, railways, gardens, open space,

Table 2. Species of Hemiptera recorded on urban Bracknell roundabouts and related sites

Species identity	Number of individuals	Number of sites
Suborder Sternorrhyncha		
Superfamily Psylloidea		
Family Aphalaridae		
Rhinocola aceris (L.)	10	4
Family Psyllidae		
Cacopsylla fulguralis (Kuwayama)	11	5
Psylla alni (L.)	6	1
Psylla brunneipennis Edwards	5	4
Psylla foersteri Flor	9	1
Psylla hartigi Flor	14	6
Psylla mali Schmidberger	83	4
Psylla melanoneura Förster	42	11
Psylla peregrina Förster	133	9
Psylla pulchra (Zetterstedt)	2	1
Psylla sorbi (L.)	155	6
Psyllopsis discrepans (Flor)	4	1
Psyllopsis fraxini (L.)	12	3
Psyllopsis fraxinicola (Förster)	95	6
Psylla sp.	1	1
Psyllopsis sp.	9	2
Family Triozidae		
Trioza rhamni (Schrank)	1	1
Trioza urticae (L.)	23	7
Suborder Auchenorrhyncha		
Family Cercopidae		
Aphrophora alni (Fallén)	1	1
Neophilaenus lineatus (L.)	9	5
Philanenus spumarius (L.)	6	4
Family Cicadellidae		
Subfamily Megophthalminae		
Megophthalmus scanicus (Fallén)	9	3
Subfamily Idiocerinae		
Idiocerus albicans Kirschbaum	2	1
Idiocerus confusus Flor	1	1
Idiocerus populi (L.)	1	1
Subfamily Macropsinae		
Macropsis infuscata (J. Sahlberg)	2	1
Oncopsis carpini (J. Sahlberg)	6	3
Oncopsis avellanae Edwards	1	1
Oncopsis subangulata (J. Sahlberg)	10	6
Oncopsis tristis (Zetterstedt)	3	1
Pediopsis tiliae (Germar)	1	1
Subfamily Agalliinae		
Agallia ribauti Ossiannilsson	7	3
Subfamily Aphrodinae		
Aphrodes albifrons (L.)	17	4
Aphrodes bicinctus (makarovi) (Schrank)	11	3
Aphrodes flavostriatus (Donovan)	1	1
Aphrodes serratulae (Fabricius)	71	12
Subfamily Deltocephalinae		
Arthaldeus pascuellus (Fallén)	28	8
Athysanus argentarius Metcalf	2	1

Table 2. *(continued)*

Species identity	Number of individuals	Number of sites
Balclutha punctata (Fabricius)	2	1
Deltocephalus pulicaris (Fallén)	34	8
Euscelis incisus (Kirschbaum)	34	7
Psammotettix confinis (Dahlbom)	1	1
Streptanus marginatus (Kirschbaum)	3	3
Streptanus sordidus (Zetterstedt)	8	3
Macrosteles sp.	2	1
Psammotettix sp.	2	1
Subfamily Typhlocybinae		
Alebra albostriella (Fallén)	31	4
Alebra wahlbergi (Boheman)	43	4
Alnetoidia alneti (Dahlbom)	135	6
Arboridia ribauti (Ossiannilsson)	2	2
Dikraneura variata Hardy	7	2
Edwardsiana crataegi (Douglas)	26	6
Edwardsiana frustrator (Edwards)	1	1
Edwardsiana hippocastani (Edwards)	1	1
Edwardsiana prunicola (Edwards)	3	2
Edwardsiana rosae (L.)	1	1
Edwardsiana salicicola (Edwards)	1	1
Edwardsiana spinigera (Edwards)	1	1
Empoasca decipiens Paoli	1	1
Empoasca vitis (Göthe)	4	3
Eupteryx notata Curtis	3	2
Eupteryx urticae (Fabricius)	2	2
Eurhadina loewii (Then)	1	1
Eurhadina pulchella (Fallén)	7	2
Fagocyba cruenta (Herrich-Schaeffer)	38	13
Kyboasca bipunctata (Oshanin)	8	1
Kybos betulicola (Wagner)	3	1
Kybos populi (Edwards)	1	1
Kybos strigilifer (Ossiannilsson)	2	1
Lindbergina aurovittata (Douglas)	1	1
Ossiannilssonola callosa (Then)	2	2
Ribautiana debilis (Douglas)	10	4
Ribautiana scalaris (Ribaut)	7	2
Ribautiana tenerrima (Herrich-Schaeffer)	8	4
Ribautiana ulmi (L.)	12	1
Typhlocyba bifasciata Boheman	1	1
Typhlocyba quercus (Fabricius)	3	2
Zygina flammigera (Geoffroy in Fourcroy)	1	1
Zyginidia scutellaris (Herrich-Schaeffer)	41	6
Edwardsiana sp.	11	6
Kybos sp. (*virgator/strigilifer/calyculus*)	1	1
Kybos sp. (*rufescens/butleri*)	1	1
Kybos sp. (*smargdula/betulicola*)	2	1
Zygina (*angusta/ordinaria*)	4	1
Family Delphacidae		
Dicranotropis humata (Boheman)	1	1
Javesella pellucida (Fabricius)	5	5
Javesella dubia (Kirschbaum)	1	1
Kosswigianella exigua (Boheman)	2	2

Table 2. *(continued)*

Species identity	Number of individuals	Number of sites
Struebingianella dalei (Scott)	21	2
Xanthodelphax stramineus (Stål)	2	1
Javesella sp.	7	7
Muellerianella sp.	4	2
Suborder Heteroptera		
Family Tingidae		
Physatocheila dumentorum (Herrich-Schäffer)	6	2
Family Microphysidae		
Loricula elegantula (Bärensprung)	1	1
Family Miridae		
Amblytylus nasutus (Kirschbaum)	1	1
Atractotomus mali (Meyer-Dür)	6	2
Campyloneura virgula (Herrich-Schäffer)	5	3
Capsus ater (L.)	1	1
Chlamydatus saltitans (Fallén)	7	4
Deraecoris flavilinea (A. Costa)	24	8
Lygocoris contaminatus (Fallén)	12	6
Lygocoris populi Leston	7	2
Lygocoris rugicollis (Fallén)	18	1
Lygus rugulipennis Poppius	1	1
Magaloceroea recticornis (Geoffroy)	2	1
Notostira elongata (Geoffroy)	11	4
Orthocephalus saltator (Hahn)	2	1
Pithanus maerkelii (Herrich-Schäffer)	14	3
Phoenicocoris obscurellus (Fallén)	14	2
Phylus coryli (L.)	14	4
Phylus pallipes Fieber	1	1
Phylus melanocephalus (L.)	2	2
Pinalitus cervinus (Herrich-Schäffer)	6	2
Plagiognathus arbustorum (Fabricius)	4	1
Plagiognathus chrysanthemi (Wolff)	8	3
Psallus assimilis Stichel	1	1
Psallus betuleti (Fallén)	3	3
Psallus confusus Rieger	4	1
Psallus flavellus Stichel	3	2
Psallus lepidus (Fieber)	9	5
Psallus mollis (Mulsant & Ray)	1	1
Psallus varians (Herrich-Schäffer)	10	4
Orthotylus flavinervis (Kirschbaum)	2	1
Orthotylus marginalis Reuter	12	2
Orthotylus tenellus (Fallén)	2	2
Orthotylus viridinervis (Kirschbaum)	3	2
Stenodema calcarata (Fallén)	1	1
Sthenarus rotermundi (Scholtz)	10	2
Psallus sp. (*confusus*/*mollis*)	5	2
Family Nabidae		
Himacerus mirmicoides (O. Costa)	2	1
Family Anthocoridae		
Anthocoris confusus Reuter	2	2
Anthocoris nemorum (L.)	10	5
Anthocoris nemoralis (Fabricius)	2	2
Cardiastethus fasciiventris (Garbiglietti)	3	3

Table 2. *(continued)*

Species identity	Number of individuals	Number of sites
Tetraphleps biscuspis (Herrich-Schäffer)	1	1
Orius sp.	1	1
Family Berytidae		
Berytinus sp. nymph	4	2
Family Lygaeidae		
Kleidocerys resedae (Panzer)	103	5
Megalonotus chiragra (Fabricius)	1	1
Orsillus depressus Dallas	2	1
Scolopostethus affinis (Schilling)	1	1
Family Coreidae		
Coriomerus denticulatus (Scopoli)	1	1
Gonocerus acuteangulatus (Goeze)	1	1
Family Pentatomidae		
Palomena prasina (L.)	2	2
Podops inuncia (Fabricius)	1	1
Family Acanthosomatidae		
Acanthosoma haemorrhoidale (L.)	3	1
Elasmostethus tristriatus (Fabricius)	1	1
Elasmucha grisea (L.)	2	2

woodland and open water. Using a 1:25 000 scale map (Ordnance Survey, Explorer Series, map number 160), the land use was recorded every 1 mm on the map for 4 cm, equivalent to 1 km, along north, east, south, west transects from each of the 18 sites.

Results

The species and number of individuals of Hemiptera recorded are shown in Table 2. Only four species were collected during both tree and grassland sampling: *Philaenus spumarius* (L.), *Balclutha punctata* (F.), *Alebra wahlbergi* (Boheman) and *Psallus betuleti* (Fallén). In total 1336 individuals of 96 species were recorded from trees, and 635 individuals of 46 species were found in grassland. Of these, 67 species were Auchenorrhyncha, 55 were Heteroptera and 16 were Psylloidea. A further 49 species have either been found during previous unsystematic field collecting, or were recorded at the field sites but not during the sampling procedure, and these are shown in Table 3. Addition of the these further species increases the known Bracknell species richness totals to 81 Auchenorrhyncha, 89 Heteroptera and 17 Psylloidea.

Species richness estimates are given in Table 4. Observed species-richness values given in Table 4 are slightly different from those given above, because those in the table are from the EstimateS analyses which included a number of species which could be identified as being one of two or more species, both or all of which were not found elsewhere, but could not be specifically named with certainty. For example this occurred in the case of the four female specimens of *Muellerianella* planthoppers (*M. brevipennis* (Boheman) or *M. fairmairei* (Perris)), as these are distinguishable from other female delphacids but only the males of these species can be identified specifically (Booij, 1981).

Table 4 also shows species-richness estimate values, standard deviation and 95% confidence limits. Auchenorrhyncha estimates varied from 91–111 species, while for Heteroptera and Psylloidea the range was between 67–86 and 16–25, respectively.

Table 3. Species of Hemiptera found during unsystematic sampling in Bracknell at different locations and at times outside the sampling period, between 1996–2002

Suborder Auchenorrhyncha
Cicadellidae
Adarrus ocellaris (Fallén)
Agurialiana stellulata (Burmeister)
Eupterycyba jucunda (Herrich-Schaeffer)
Eupteryx aurata (L.)
Graphocephala fennahi Young
Graphocraerus ventralis (Fallén)
Grypotes puncticollis (Herrich-Schaeffer)
Hauptidia maroccana (Melichar)
Iassus lanio (L.)
Macrosteles viridigriseus (Edwards)

Delphacidae
Conomelus anceps (Germar)
Ditropis pteridis (Spinola)

Issidae
Issus coleoptratus (Fabricius)

Cixiidae
Tachycixius pilosus (Olivier)

Suborder Heteroptera
Acanthosomatidae
Elasmostethus interstinctus (L.)

Aradidae
Aradus depressus (Fabricius)

Coreidae
Coreus marginatus (L.)

Cydnidae
Legnotus limbosus (Geoffroy)

Lygaeidae
Heterogaster urticae (Fabricius)
Stygnocoris rusticus (Fallén)

Miridae
Blepharidopterus angulatus (Fallén)
Calocoris striatellus (Fabricius)
Cyllecoris histrionius (L.)
Deraeocoris lutescens (Schilling)
Deraeocoris ruber (L.)
Dicyphus epilobii Reuter
Dicyphus pallicornis (Fieber)
Dryophilocoris flavoquadrimaculatus (DeGeer)
Harpocera thoracica (Fallén)
Heterocordylus tibialis (Hahn)
Heterotoma planicornis (Pallas)
Liocoris tripustulatus (Fabricius)
Malacocoris chlorizans (Panzer)
Miris striatus (L.)
Monalocoris filicis (L.)
Orthops campestris (L.)
Phytocoris tiliae (Fabricius)
Psallus ambiguus (Fallén)
Psallus perrisi (Mulsant & Rey)
Stenodema laevigata (L.)

Pentatomidae
Aelia acuminata (L.)
Dolycoris baccarum (L.)
Eurydema oleracea (L.)
Eysarcoris fabricii (Kirkaldy)
Palomena prasina (L.)
Pentatoma rufipes (L.)
Piezodorus lituratus (Fabricius)

Rhopalidae
Rhopalus subrufus (Gmelin)

Suborder Sternorrhyncha
Superfamily Psylloidea
Psyllidae
Arytainilla spartiophila (Förster)

The mean value of the four estimators is also given. For Heteroptera and Psylloidea the Jack-knife 1 estimates were closest to the mean value, while for Auchenorrhyncha it was Chao 2, closely followed by Jack-knife 1. The standard deviation was consistently lower for Jack-knife 1 than for the other estimators, with the exception of Chao 1 for Psylloidea. No standard deviation is given for Chao 2, as this is not calculated by EstimateS version 6.0b1.

Species richness estimates for Auchenorrhyncha and Heteroptera from the two principal habitat types, grassland and arboreal, are shown in Table 5. Table 6 shows the comparison between the species richness estimates using all samples, and by combining the estimates from grassland and arboreal samples. For Auchenorrhyncha

Table 4. Observed and estimated species-richness of Hemiptera on Bracknell roundabouts, using all samples

Estimator	Auchenorrhyncha	Heteroptera	Psylloidea
Chao 1	91.0	66.7	16.3
Standard deviation	12.8	7.6	1.3
95% confidence interval	25.0	14.9	2.6
Chao 2	97.0	75.1	24.3
Standard deviation	14.3	11.8	17.1
95% confidence interval	28.1	23.2	33.6
Jack-knife 1	96.8	75.8	21.0
Standard deviation	4.7	4.7	2.2
95% confidence interval	9.3	9.3	4.3
Jack-knife 2	110.7	85.8	24.9
Standard deviation	–	–	–
95% confidence interval	–	–	–
Observed species richness	70	56	16
Mean of estimators	98.9	75.8	21.6
Difference between observed and Jack-knife 1	26.8	19.8	5.0
Difference as % of estimated (Jack-knife 1)	27.7	26.2	23.7

Table 5. Observed and estimated Hemiptera species-richness from grassland and arboreal habitats on Bracknell roundabouts

Estimator	Auchenorrhyncha		Heteroptera	
	Grassland	Arboreal	Grassland	Arboreal
Chao 1	35.0	61.1	23.0	39.6
Standard deviation	8.3	12.2	4.8	2.8
95% confidence interval	16.2	24.0	9.4	5.5
Chao 2	37.0	69.9	30.6	41.3
Standard deviation	9.0	16.4	12.5	4.0
95% confidence interval	17.7	32.0	24.4	7.8
Jack-knife 1	36.8	64.8	27.7	45.9
Standard deviation	2.7	4.1	2.9	3.5
95% confidence interval	5.3	8.0	5.7	6.8
Jack-knife 2	41.7	77.6	33.5	46.0
Standard deviation	–	–	–	–
95% confidence interval	–	–	–	–
Observed species richness	28	44	19	37
Difference between observed and Jack-knife 1	8.8	20.8	8.7	8.9
Difference as % of estimated (Jack-knife 1)	24.0	32.1	31.5	19.4

the sum of the habitat based estimates were consistently higher that estimates based on all arboreal samples, whereas for the Heteroptera they were lower. For both groups the Jack-knife 1 estimates showed the closest agreement.

Table 7 shows the results of regressions between log (ln) species-richness estimate values, based on all samples, and both log (ln) area and log (ln) tree species richness at the 18 sites. All regressions were significant. The area regression (species-area

Table 6. Comparison of species-richness estimates using all samples and from using the sum of habitat-based estimates

Estimator	Auchenorrhyncha	Heteroptera
Chao 1		
All samples	91	66.71
Grassland + arboreal samples	96.07	62.58
Difference	−5.07	4.13
Chao 2		
All samples	97	75.05
Grassland + arboreal samples	106.94	71.83
Difference	−9.94	3.22
Jack-knife 1		
All samples	96.83	75.83
Grassland + arboreal samples	101.64	73.64
Difference	−4.81	2.19
Jack-knife 2		
All samples	110.74	85.75
Grassland + arboreal samples	119.35	79.47
Difference	−8.61	6.28

Table 7. Regressions between log (ln) arboreal Hemiptera species-richness estimates and both log (ln) roundabout area and log (ln) number of tree species at each roundabout

Comparison	Estimator	t	p	r^2	d.f.
Area	Chao 1	2.52	$p<0.05$	0.30	1,15
	Chao 2	2.47	$p<0.05$	0.29	1,15
	Jack-knife 1	2.99	$p<0.01$	0.37	1,15
	Jack-knife 2	2.85	$p<0.05$	0.35	1,15
Tree species richness	Chao 1	8.52	$p<0.001$	0.83	1,15
	Chao 2	8.17	$p<0.001$	0.82	1,15
	Jack-knife 1	10.25	$p<0.001$	0.88	1,15
	Jack-knife 2	10.33	$p<0.001$	0.88	1,15

Table 8. Mean (±SE) land use found within 1 km of the 18 sample sites

Land use type	Mean	% area
Water	0.6	(0.4)
Strongly man affected habitats		
Road/railway	26.7	(1.6)
Building	18.6	(1.6)
Total	45.3	(2.5)
Semi-natural terrestrial habitats		
Other open area	34.0	(1.9)
Garden	14.4	(1.3)
Woodland	5.7	(2.0)
Total	54.2	(2.4)

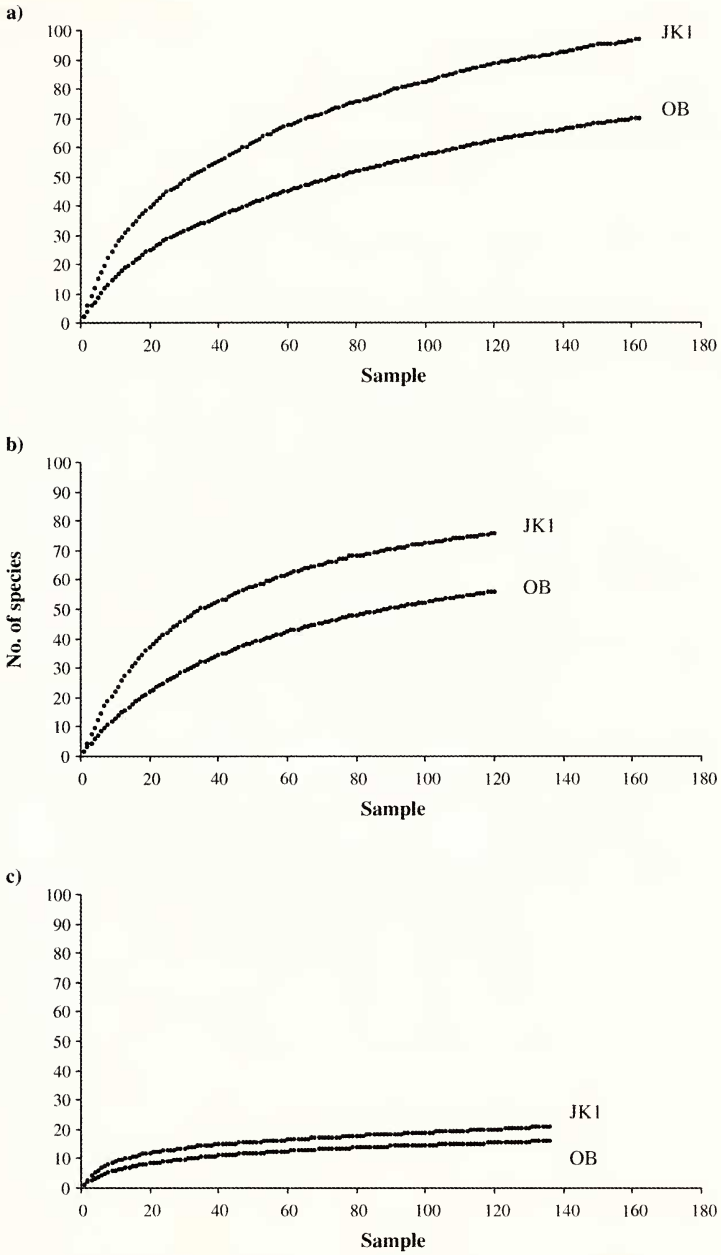

Figure 4. Observed (OB) and Jack-knife 1 species richness estimates (JK1) for the number of species of (a) Auchenorrhyncha, (b) Heteroptera and (c) Psylloidea found within Bracknell roundabouts. Estimates were calculated using all samples, both grassland and arboreal, from all sites.

relationship) with the highest t and r^2 values was that using Jack-knife 1 estimates, while for tree species richness Jack-knife 2 had the highest t and r^2 values, but these were only very slightly higher than those for Jack-knife 1.

Comparison of the four species-richness estimators in terms of overall mean estimates and their standard errors, differences between habitat-based and all sample estimates, and regressions indicated that overall the Jack-knife 1 estimator gave the best species-richness estimates for Bracknell Hemiptera. Figure 4 shows the observed and Jack-knife 1 estimated species-richness for the three Hemiptera groups. For the Auchenorrhyncha and Heteroptera both observed and estimated species-richness clearly have not reached an asymptote with the number of samples taken, indicating that further sampling would result in higher estimates (Coddington *el al.*, 1996). In contrast the estimate for the Psylloidea rises only very slowly with sample number, indicating that it is much closer to an asymptote.

Table 4 shows the difference between the observed and estimated Jack-knife 1 species richness for each Hemipteran group. These figures indicated that 27 Auchenorrhyncha, 20 Heteroptera and 5 Psylloidea species were unsampled, which would approximate to 28%, 26% and 24%, respectively, of the estimated species richness. A similar approach using habitat specific data (Table 5) indicated that the most under-sampled category was arboreal Auchenorrhyncha, with 21 species representing 32% of the estimated species-richness, remaining unsampled. A very similar proportion of the grassland Heteroptera may be unsampled but in this numerically smaller group this equated to only 9 further species. The arboreal Heteroptera appeared to be the least incompletely sampled with a further 9 species likely, equating to 19% of the estimate.

Mean percentage land use categories are shown in Table 8. Grassland, gardens and woodland together made up an average of approximately 54% of Bracknell land use, with buildings and transport infrastructure contributing around 45%.

Discussion

Notable species

Several notable species were recorded in the study, and some of these were species that have recently colonised the UK. The most recent colonist was the psyllid *Cacopsylla fulguralis* (Kuwayama), a pest of *Elaeagnus* spp., which is native to eastern Asian countries such as China, Korea and the Philippines, and was first found in the UK in 2000, having been first recorded in Europe a year earlier. By 2002 it had been recorded at a number of widely spaced locations within Britain, including Surrey, the county which borders Bracknell Forest to the south (Malumphy *et al.*, 2002; Malumphy & Halstead, 2003). In our study, eleven individuals were found at five of the sites and on five different tree species, although not on *Elaeagnus*, indicating that it may be quite widespread in the area.

Twenty-four individuals of the mirid *Deraeocoris flavilinea* (A. Costa) were recorded from eleven different species of tree at eight of the sample sites. This species was first recorded in the UK in 1996, but has subsequently been found quite frequently, having become rapidly established within this country (Jones, 1999; Miller, 2001; Nau & Brooke, 2003). Another relatively newly established species was *Orsillus depressus* Dallas (Heteroptera: Lygaeidae), which was first recorded in the UK in 1989, and which has subsequently been found in a number of sites scattered over South-East England (Hawkins, 1989; B.S. Nau, *pers. comm.*).

Gonocerus acuteangulatus (Goeze) (Heteroptera: Coreidae) has been known to be present in the UK for many years but until relatively recently was restricted to Box Hill in Surrey and has been listed as endangered (Southwood & Leston, 1959; Kirby, 1992). This species has however, shown a recent range increase, is now described as common in Surrey and has also been recorded in Kent, Middlesex and Sussex (Hawkins, 2003). It is possible that the specimen found in Bracknell is the first record of this species in Berkshire. The two most notable leafhopper species to be recorded were, *Athysanus argentarius* Metcalf and *Pediopsis tiliae* (Germar) (Auchenorrhyncha: Cicadellidae). *Athysanus argentarius* is a grassland species, which was first found in Britain in 1866, then not again until 1951. Since the 1950s until fairly recently, it was largely only recorded from coastal areas, but has now also been found in a number of inland sites having also shown an apparent range increase (Badmin, 1981; Stewart, 1987; Verdcourt, 1994; Salmon & Chapman, 2000). *Pediopsis tiliae* is an uncommon species, which feeds on lime (*Tilia* sp.), particularly Small-leaved lime (*Tilia cordata*). Interestingly in the context of the present study many records of this species come from urban or other semi-natural areas (Badmin, 1991, 1994).

Species richness

Of the four non-parametric species-richness estimators used, Jack-knife 1 appeared to the best for Bracknell Hemiptera. Generally Jack-knife 1 showed the closest values to the means of the four estimators, showed the smallest differences between estimates made using all samples and those calculated from the sum of estimates from grassland and arboreal habitats, the smallest standard deviations, and the best regressions with area and tree species-richness (Tables 4, 5, 6 & 7). Consequently Jack-knife 1 estimates were used to compare with observed species-richness.

The Hemiptera species richness in Bracknell was considerable, with the 18 study sites yielding 67 Auchenorrhyncha, 55 Heteroptera and 16 Psylloidea species (Table 2), which represented approximately 18%, 12% and 20% of the respective UK species totals for these three groups of Hemiptera (the national total of Heteroptera used excluded the aquatic and semi-aquatic species, which were not sampled in the study). These figures were the result of a single set of samples taken over a very short space of time, and hence the true species richness is likely to be somewhat higher. This is illustrated by the further 49 species that were recorded in Bracknell but outside the main study during the period 1996–2002 (Table 3). With these further species the totals rise to 81 Auchenorrhyncha, 89 Heteroptera and 17 Psylloidea, which equate to approximately 22%, 19% and 22% of the respective national totals.

Calculations of the Jack-knife 1 estimator gave species-richness figures of 97 Auchenorrhyncha, 76 Heteroptera and 21 Psylloidea, which would equate to 26%, 13% and 27% of the respective national totals. The results also indicate that the estimates had not reached an asymptote relative to the number of samples (Fig. 4), which indicates that further sampling would result in higher estimates (Coddington *et al.*, 1996). Thus our data, both in terms of actual species recorded and estimated species-richness, indicates that at least 20% of the UK Hemiptera species can be found within the town of Bracknell.

The species richness of Auchenorrhyncha found was comparable with that found during six years of suction sampling at Silwood Park, which is located 10 km to the east of Bracknell (Waloff, 1973). At Silwood Park 115 species were recorded, but this was over six complete years, and when just July catches were included this figure was

reduced to 67, which is exactly the same number of species recorded at the 18 study sites. Thus even though Bracknell is considerably more urbanised, the rather limited sampling of the present study indicated a comparable species richness to that of Silwood Park.

The difference between observed and estimated species-richness gives a measure of the number of species that occur in the sampled area but remain unrecorded. There remains some uncertainty about the number of such species unless the estimate has reached an asymptote at the level of the true species-richness (Foggo *et al.*, 2003), and consequently comparison of observed and estimated values will under-estimate the number of un-recorded species. Although the reported estimates had not reached an asymptote (Fig. 4), the difference between estimated and observed species-richness can still be useful, particularly in comparative terms, in giving at least some idea, all be it an under-estimate, of the number of un-sampled species. In this study it was estimated that 27 Auchenorrhyncha, 20 Heteroptera and 5 Psylloidea were un-recorded, which would represent 28%, 26% and 24% of the estimated totals (Table 4). Thus in all three Hemiptera groups approximately a quarter of estimated species remained un-recorded. When different habitat types were considered separately, the data indicated that arboreal Heteroptera were the most completely sampled (19% un-recorded), followed by Psylloidea and grassland Auchenorrhyncha (24%), then grassland Heteroptera and arboreal Auchenorrhyncha (32%).

The number of species found in this study and the related species richness estimates were limited by temporal, spatial and habitat related constraints. The timing of sampling is one of the most important of these. For the arboreal part of the study all the samples were taken within a nine day period in mid June, while the grasslands were sampled over three days in mid July. Given that the phenology of insect species differs, the limited sampling carried out would have meant that many species would either not have been found or would have been in the larval stages, and therefore in most cases unidentifiable. This would have been particularly the case for the grassland Auchenorrhyncha, for which adult species richness and abundance reach a peak during the late summer months of August and September (Andrzejewska, 1965; Morris, 1971, 1973; Waloff & Solomon, 1973; Morris & Lakhani, 1979; Morris, 1981a; Lawton, 1983; Sedlacek *et al.*, 1988; Morris, 1990b), and this problem is reflected in that large numbers of immature individuals were caught in the grassland samples. A further factor limiting the estimate of species richness is that the study was limited in terms of the location of sampling. At Bill Hill (7) and Mill Pond Park (11) only the trees at the edges of the areas of woodland were investigated, while at all sites sampling was restricted to trees and grassland, but many species are associated with other habitats such as bushes and herbaceous plants such as nettles (Davis, 1991).

Using Bracknell as an example of an urban area clearly shows that high species richness can be maintained within towns and cities. One of the most important factors in maintaining urban biodiversity is the proportion of open space. Davis (1978) found that species richness correlated positively with the percentage of open space within a one kilometre radius of sample sites. In this study it was found that Bracknell had approximately 54% 'open space' (Table 8), which although relatively low compared with some of the suburbs studied by Davis (1978), still indicated that approximately half of the land area was made up of grassland, woodland, verges, 'waste ground' and gardens. The fragmentation of such habitats in urban areas has a strong influence on species richness through its effect on population sizes, isolation, and the processes of colonization and extinction. The effects of fragmentation vary between different species according to their habitat specialization, trophic level,

population dynamics, rarity and dispersal ability (Davis & Glick, 1978; Steffan-Dewenter & Tscharntke, 2002). Andrén (1994, 1999), reported that relatively low levels of habitat loss and fragmentation resulted in little loss of species but when the proportion of habitat remaining fell below 20 to 30% there would be an exponential loss of species. Woodland habitat in Bracknell is very fragmented and only about 6% remains within the town (Table 8). Although areas of woodland are rare, the town does have a very large number of trees of many species, both planted and those retained during development, which provide a semi-continuous habitat throughout much of the urban area. These trees maintain the habitat connectivity that is so important in maintaining biodiversity (Andrén, 1994, 1999; Gonzalez *et al.*, 1998; Fernández-Juricic, 2000; Savard, *et al.*, 2000; Steffan-Dewenter & Tscharntke, 2002; Rudd *et al.*, 2002). Connectivity in grassland habitats is to some extent maintained by gardens, parks and other open areas and by road verges, but these areas are very variable in their quality because of the differing level of management, which has a very strong effect of grassland Hemiptera abundance and species richness (Morris, 1979, 1981a, 1981b, 2000; Helden & Leather, 2004). Despite this, the relatively high level of open habitat and good dispersal ability of many species (Morris, 1990a) are likely to be important factors in maintaining grassland Hemiptera diversity within Bracknell.

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***Gerris lateralis* Schummel (Hemiptera: Gerridae) in Hampshire.** – The Wildgrounds are part of the Alver Valley, Gosport, South Hampshire (VC11) (SU5800) and include an area of fen, with shallow flooded swampy ground dominated by *Carex acutiformis*. On the 26.iv.2005, I took several wingless pond-skaters at the base of the emergent sedges. These proved to be *G. lateralis*, which according to the recent Atlas (Huxley, 2003, *Provisional Atlas of the British Aquatic bugs (Hemiptera, Heteroptera)*. Huntingdon: BRC), are the first modern records from Hampshire. The previous most southerly record was made by Peter Kirby, in 1997 in Berkshire, close to the border with North Hampshire. I am unaware of any old Hampshire records.

These observations were entirely consistent with my previous experience of the insect in Cumbria and North Norfolk, with adults active on slimy mud and duckweed-covered shallow water. – JONTY DENTON, Kingsmead, Wield Road, Medstead, Hampshire, GU34 5NJ.

Dark form of Waved Carpet *Hydrelia sylvata* (D. & S.) (Lepidoptera: Geometridae) in Perry Woods, Kent. – A dark form of this Nationally Scarce B geometer was recorded in my Rothamsted light-trap in Perry Woods on the night of 5.vii.2005 (det. A. Pickles). This is the first record of this species from this locality following > 20 years of continuous light-trapping. Ferguson in his most recent *Kent Moth Report 2003* (2005) records *H. sylvata* from 16 ten-km squares in the county, indicating that it is now more widespread in the South-East than perceived a few years ago. Some of this range in-filling is due to more thorough recording, but also represents a noticeable spread of the moth. Its predilection for Sweet chestnut *Castanea sativa* probably accounts for its presence in Perry Woods and it will be interesting to see whether it becomes firmly established here. This was certainly the case for the Least Carpet *Idaea rusticata* (D. & S.) which first appeared in Perry Woods in 1994 and is now one of the most regularly appearing species of the genus. The records for 2005 show that it appeared on 16 nights during July–August with a total of 31 individuals. – JOHN BADMIN, Coppice Place, Selling, Kent ME13 9RP